Intelligent Automation Approach for Improving Pilot Situational Awareness

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Abstract

Automation in the aviation domain has been increasing for the past two decades. Pilot reaction to automation varies from highly favorable to highly critical depending on both the pilot's background and how effectively the automation is implemented. We describe a user-centered approach for automation that considers the pilot's tasks and his needs related to accomplishing those tasks. Further, we augment rather than replace how the pilot currently fulfills his goals, relying on redundant displays that offer the pilot an opportunity to build trust in the automation. Our prototype system automates the interpretation of hydraulic system faults of the UH-60 helicopter. We describe the problem with the current system and our methodology for resolving it.

Introduction

Modern aircraft feature a variety of automation technologies to help the pilot with such things as checklist execution, navigation, descent planning, engine configuration, and system monitoring. Older aircraft can be retrofitted to incorporate many of these features by replacing older radios with modern units, replacing traditional gauges with computer monitors, and linking everything with computer processors. One of the goals of automation is to improve the pilot's situational awareness. A related goal is to decrease the workload required to maintain a given level of awareness. Technologies assist the pilot with awareness of position, terrain, traffic, fuel usage and remaining aircraft range, engine operating characteristics, etc.

Pilots have various reactions to automation. They may find it superfluous (the "real pilots don't need an autopilot" perspective), helpful ("the autopilot can fly an approach much more accurately than I; a real plus in bad weather" perspective), or confusing (the "what's it doing now?" perspective). We believe that to make automation helpful, it needs to fulfill a pilot's need, fit seamlessly into the flying tasks, and be easy enough to understand to earn a pilot's trust. Using this user-centered approach, we developed a system to assist a helicopter pilot in the task of recognizing and properly reacting to hydraulic system failures. It eases the pilot's task by quickly interpreting the same signals he uses to identify a failure and by explicitly providing not just the type of failure but also the desired emergency procedures and any flight limitations. The traditional display of the failure remains available to the pilot; this redundant display of information enables him to use just the parts of the new display he chooses or to verify the automation's result and build trust of it gradually.

In the following sections, we define situational awareness and provide an overview of measurement factors, describe the system and the problem with that system that we are addressing, present our methodology for solving the problem and evaluating our solution, and conclude with areas of related future work.

Situational Awareness

Situational awareness (SA) can be hierarchically decomposed into three levels. To achieve the initial level of SA requires that the pilot perceives relevant environmental information (e.g., state of a subsystem, existence of terrain, presence of traffic, etc.). The next higher level requires that he be able to integrate the lower level information and understand how it affects his current task. The ultimate highest-level SA requires the pilot use that understanding to direct further perception and anticipate future events.[1] As an example, a pilot with level 1 SA notices the fuel level in the selected tank is low; a pilot with level 2 SA understands that the rate of fuel usage is higher than expected and he must switch to a tank with more fuel; and a level 3 SA pilot determines that he is unlikely to reach his destination due to the unexpected rate of fuel usage and must divert to an alternate airport prior to engine failure.

Workload to accomplish the various levels of SA can be measured by a number of factors including physical demand, mental demand, time pressure, effort expended, performance level achieved, frustration experienced, and annoyance experienced. Through our work, we aim to decrease mental demand, decrease effort expended, and increase the performance level achieved by the pilot in interpreting the state of a Sikorsky UH-60 subsystem and recalling the effects of any failures.

The System

The Sikorsky UH-60 Black Hawk, shown in Figure 1, is the primary troop transport in the U.S. Army. Variants of the UH-60 are used by the U.S. Air Force (Pave Hawk), U.S. Navy and Coast Guard (Seahawk), rescue and firefighting organizations (Firehawk), and international customers. The Black Hawk is designed for crew survivability and its engines, rotors, and transmission are highly capable of taking damage. Either of its twin turbine engines can keep the helicopter airborne if the other fails, the flight controls are ballistically hardened, the fuel system is crash resistant and self-sealing, and it has widely-separated redundant electronic and hydraulic systems. In this work, we focus on the hydraulic system.

Figure 1: Sikorsky UH-60 helicopter

The hydraulic system provides hydraulic pressure to operate the primary servos, tail rotor servos, pilot assist servos, and APU start motor. There are three redundant hydraulic systems: the number 1 or first stage, the number 2 or second stage, and the backup. The major components shared by these three systems (shown in **Figure 4**) include three hydraulic pump modules, two transfer modules, a utility module, a pilot-assist module, three primary servos, a tail rotor servo, four pilot-assist servos, an APU accumulator, an APU handpump, and a refill handpump. A leak detection and isolation (LDI) feature is built into the hydraulic system using pressure switches on the pump modules, check valves and shutoff valves in the transfer modules, and electronic logic

modules. When a pressure switch senses a pressure loss in the system, the logic module will shut off appropriate valves to isolate the leak and automatically turn on the backup pump.

The Problem

Two related mechanisms assist the Blackhawk pilot in determining the status of the hydraulic system: the leak detection and isolation (LDI) subsystem assists pilots in determining the location of a fluid leakage, and pressure and level sensors inform the pilot of other types of failures. Each anomalous condition results in one or more advisories appearing on the *caution and advisory panel,* shown in Figure 2.

Figure 2: Caution/Advisory Panel showing end-state for leak in the #2 primary servos.

The panel has 82 unique messages, such as "#1 fuel low" or "back-up rsvr low." Fifteen of these messages are specific to the hydraulic subsystem and encode 23 anomalies. The end-state for an anomaly can be encoded by as few as one message or as many as nine with an average of five; intermediate states can have as many as thirteen messages turn on and off prior to reaching the end-state. A centrally-located master warning light alerts the pilot of the appearance of a message on the panel; the pilot must then infer the problem based on the displayed caution and advisory messages. This inference relies on extensive training and on what Don Norman refers to as knowledge in the head.[2] Although straightforward in the single-message anomaly situation, in stressful situations, such as those caused by mission-altering anomalies, the pilot's workload is increased by the demands of determining the problem and remembering the associated emergency procedures and operating limitations.

The Methodology

Our approach to resolving the problem of relying on knowledge in the head is to transfer the knowledge into the world. Specifically, we explicitly provide the pilot with a description of the problem, the associated emergency procedures, and a reminder of any operating limitations.

Anomalous situations can be detected by examining both the state of all sensors and the outputs of the LDI subsystem. Alternatively, they can be detected by observing the processed values sent to the *caution and advisory panel*. We utilize the second approach. Using these signals and the knowledge that the set of messages associated with each problem is deterministic, an anomaly can be interpreted via a state transition diagram. The states represent the hypothesis about the anomaly as described by the signals already observed and the signals are used to transition from one hypothesis to a more fitting one. The pilot is informed upon entering a state that describes a known anomaly. If further signals are received (that is, further messages are displayed on the panel), the description given to the pilot is updated to reflect the additional knowledge.

In addition to presenting the pilot with a description of the anomalous situation, our system also presents a list of associated emergency procedures and corresponding operating limitations. Figure 3 shows the display of detected problem, suggested actions, and limitations. The pilot can scroll back through the "detected problem" segment to recall previous problems. Moreover, rather than displaying operating limitations that consider only the most recent problem, new limitations can be combined with previous limitations to further decrease the pilot's workload in determining the desired reaction.
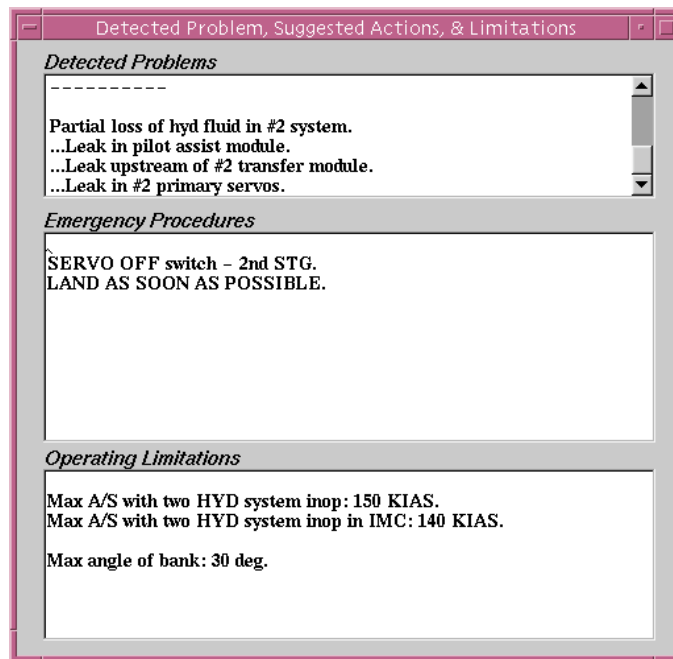

Figure 3: Display of problem description, emergency procedures, and operating limitations.

Evaluation

In order to test our approach, we simulated the hydraulic system from the perspective of the pilot. Using the graphical interface shown in Figure 4, we can inject failures and evaluate the response.
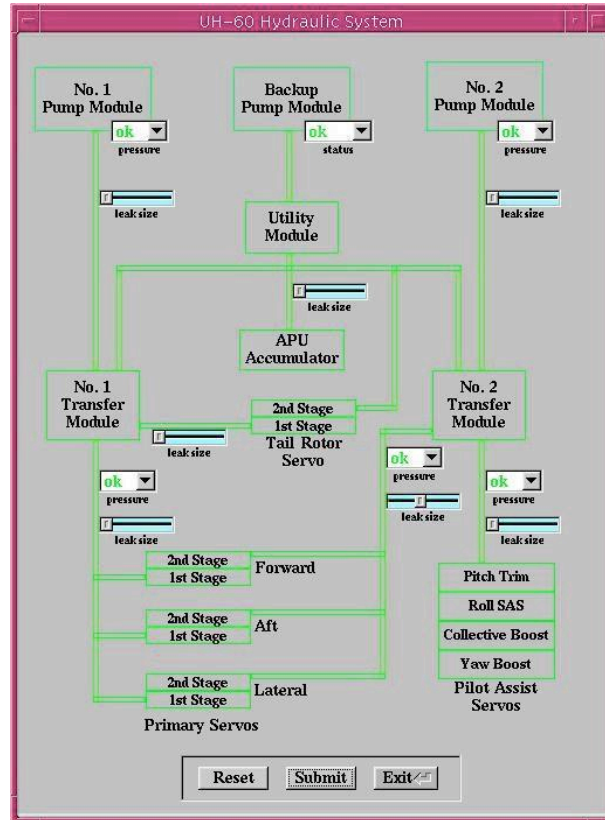

Figure 4: Simulator for UH-60 Hydraulic System.

Pressure switch detectable failures are simulated by the various pull-down pressure menus. The backup pump module has the options of "ok" or "failed" while the rest of the modules have the options of "ok" or "low." Multiple pumps can be failed simultaneously to simulate dual or triple pump failure scenarios. Alternately, LDI detectable failures are controlled by the "leak size" sliders with the slider positioned on the far left for no leak, far right for a large leak, and at intermediate positions for a comparatively smaller leak. If a leak is detected, the LDI turns off valves in a predefined order and checks the effect on continued pressure loss. Thus, from the LDI perspective, the size of the leak affects how quickly it is able to isolate the leak to its true location. As the LDI turns various valves and the backup pump off or on, corresponding messages appear on the caution/advisory panel. Thus, from a pilot's perspective, the size of the leak affects how quickly messages appear and disappear. Our simulator imitates the timing behavior and is a fair reproduction of what a pilot sees in the actual helicopter.

The hypothesis of our work is that we can improve a Black Hawk pilot's situational awareness by automatically determining a hydraulic system failure given the sequence of messages on the caution/advisory panel and then explicitly displaying necessary information about emergency procedures and operating limitations. Via our

simulator, we are able to demonstrate the accurate performance of the interpretation and instantaneous display.

Empirical evaluation of the degree of improvement to the pilot's situational awareness requires either access to panel messages from a high fidelity Black Hawk simulator or hardware propagation of the message signals as input to our interpretation algorithm. A joint NASA and Army rotorcraft research program has available a modified UH-60 known as RASCAL, Rotorcraft Aircrew Systems Concepts Airborne Laboratory. RASCAL is highly instrumented and serves as a platform to test alternative displays to improve the pilot's interface to the helicopter systems. Previous studies have accessed panel messages dealing with the transmission system in order to demonstrate automated diagnosis of transmission problems.[3] Upon establishing access to hydraulic system messages, we will conduct comparison studies to evaluate both the degree of SA improvement and the degree of workload reduction. The results of these studies will be published in a subsequent paper.

Conclusions

It has been demonstrated in various fields that productivity can be greatly enhanced through the use of automation technologies. In order to be fully accepted in aviation, automation not only needs to increase productivity but do so cooperatively with the pilot. That is, the pilot must know what the automation is currently doing and what it will do in the future. Although the Flight Management System (FMS) has been a feature of commercial airliners for decades, it is still not unusual to hear conversations where one pilot is asking the other "What's it doing?"[4] or confessing to the air traffic controller that "We're just as surprised as you were to see the computer turn us that way."[5] To avoid this situation, our approach to automation focuses on the user's needs for both performance and awareness. Rather than replacing what the pilot currently does, we augment his capabilities with displays that back up his internal knowledge. In other work, we incorporate intelligence that eliminates the need for the pilot to perform tedious computations and visualize the results in ways that the pilot can instantly and continuously determine the results of the computation and their effects on his flight.[6] Pilot evaluations will determine whether this approach produces effective decision support systems or continues to lead to what has been described as "clumsy automation."[7] In future work, we will explore incorporating other awareness and decision support systems, and presenting aircraft system status via additional modalities such as sonification and tactile methods.

References

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Acknowledgements